VLHC Magnet Workshop Summary

Why are we here?

- **Why do we care so much about superconducting magnets?**

  - **Chris Hill reminded us not to believe those who claim to know all the answers. We will need to advance to the next energy scale.**

  - **The VLHC is the only <u>sure</u> way to the next energy scale.**

  - **Superconducting magnets is the enabling technology of hadron colliders and the VLHC.**

VLHC Magnet Workshop Summary

Where are we in SC magnet R&D?

- **We are beginning a rich and varied R&D program in the U.S.** **Is it too varied?**
- **No! At our present level of understanding it is good to have a diverse program:**
  - o We are at the beginning of a long and possibly difficult research, development and planning effort.
  - o We don't know what the best, or even a good direction is — in spite of the fact that each individual knows the only right answer.
  - o Some of the technologies are so difficult that they are really experiments, not development. Some may fail!
- **It is too early to make the NLC mistake.**
- **It is too early to restrict the possibilities.**

VLHC Magnet Workshop Summary

What's happened since the last magnet workshop?

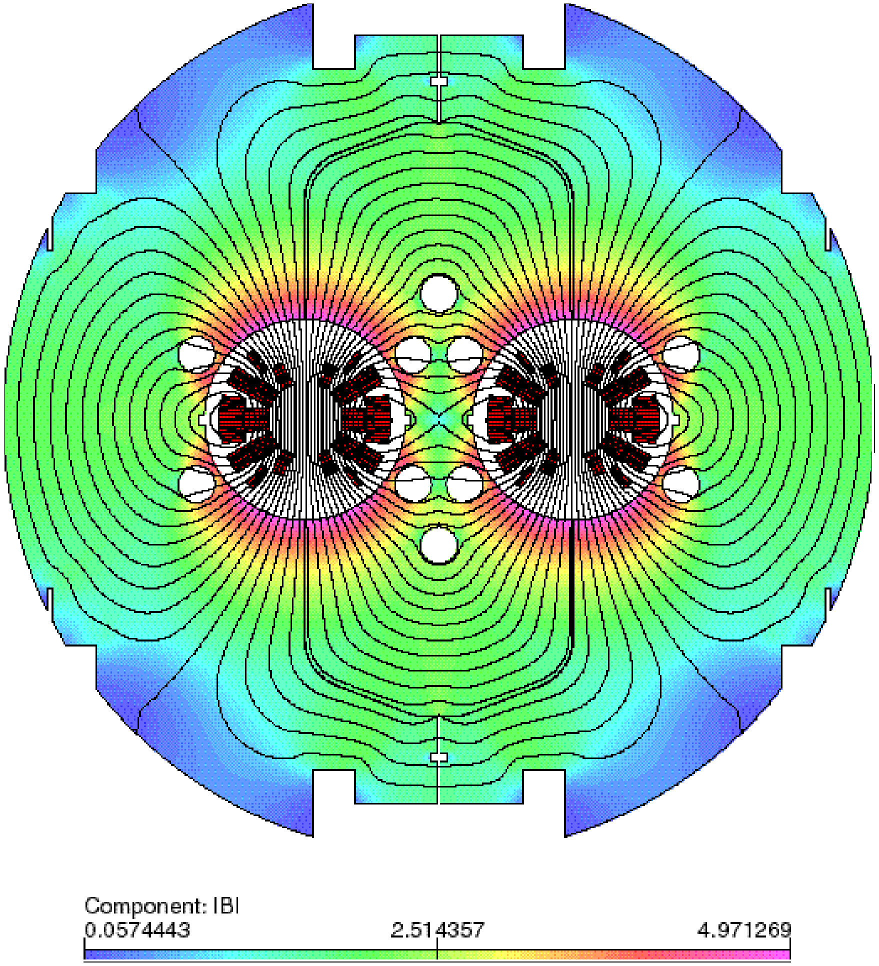
This is a personal view.

❖ We still have not made any significant magnets!

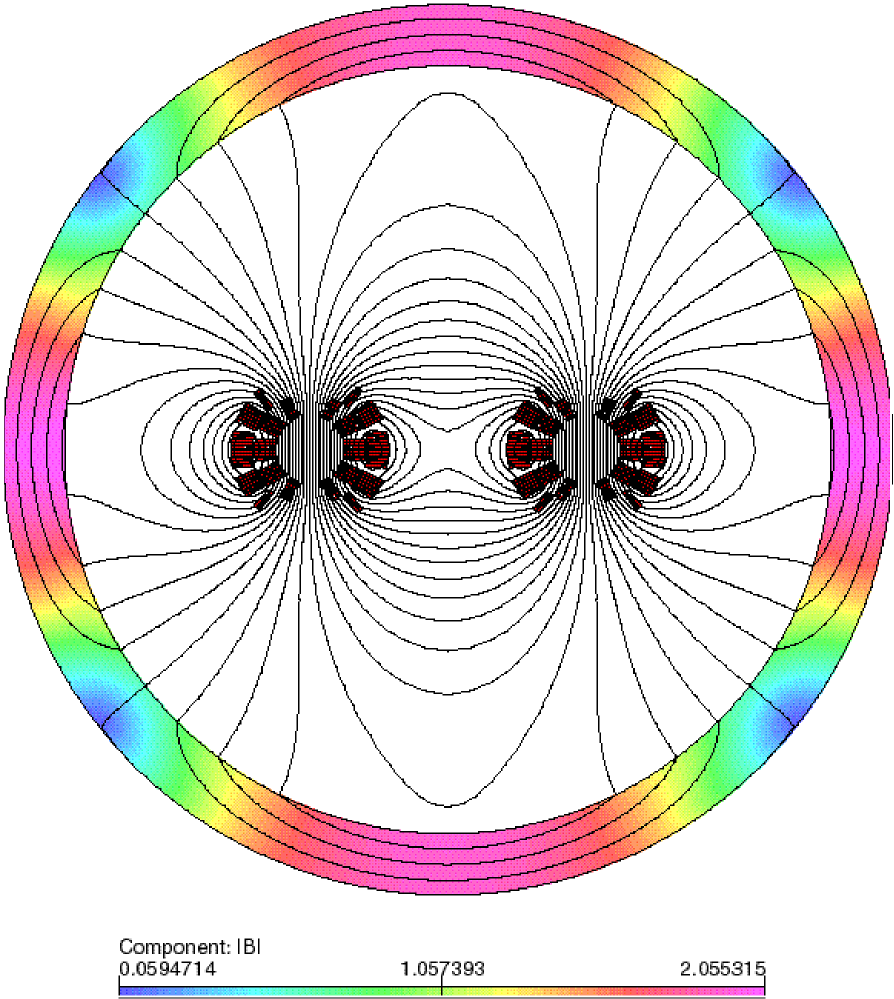
- o ***Making magnets is the first order of business.***
  - *4 years since Snowmass '96.*
  - *6 years since the Indiana University meeting;*

❖ **It takes a long time to develop good magnets and magnet systems.**

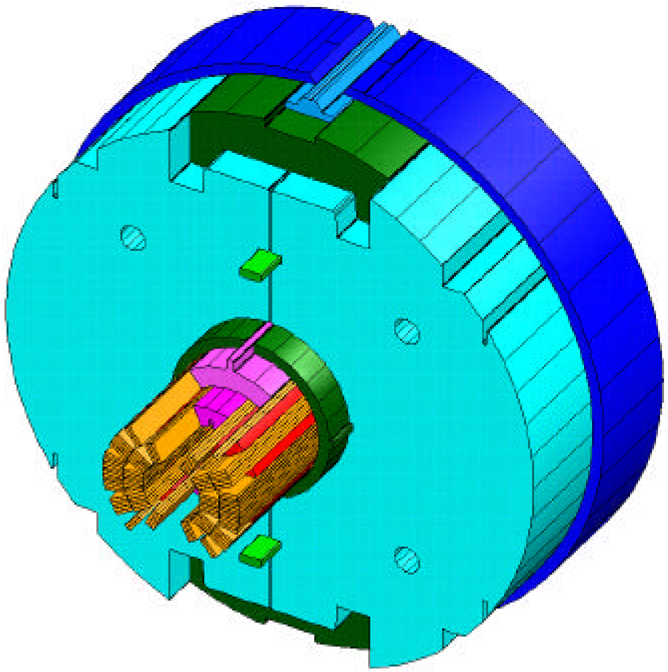
Double-bore Nb_3Sn cos-theta magnet - cold iron



Double bore Nb_3Sn cos-theta magnets - warm iron



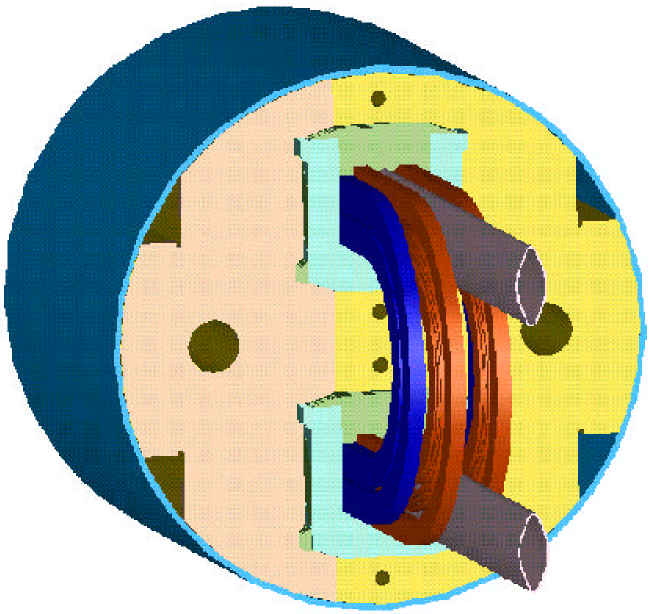
Cos-theta Design – Single Aperture



- -Field: Bmax=12.2 T at 21.98 kA
- -Good field region: DB/B<10^{-4} @ f<3cm
- -Design: two-layer cos-theta type
- -Coil bore diameter: 43.5 mm
- -Coil cross-section per bore: 2233 mm^2
- -Strand: Nb_3Sn, f1.00 mm,
  Ic(12T;4.2K)=700-800A (1.8-1.9kA/mm^2)
- -Cable: N=28, 1.80*14.24 mm^2 (keystone)
- -Insulation: high temperature ceramic
- -Wind & React technique
- -New magnet assembling technology
  (ceramic binder)
- -Fermilab/KEK/LBNL collaboration

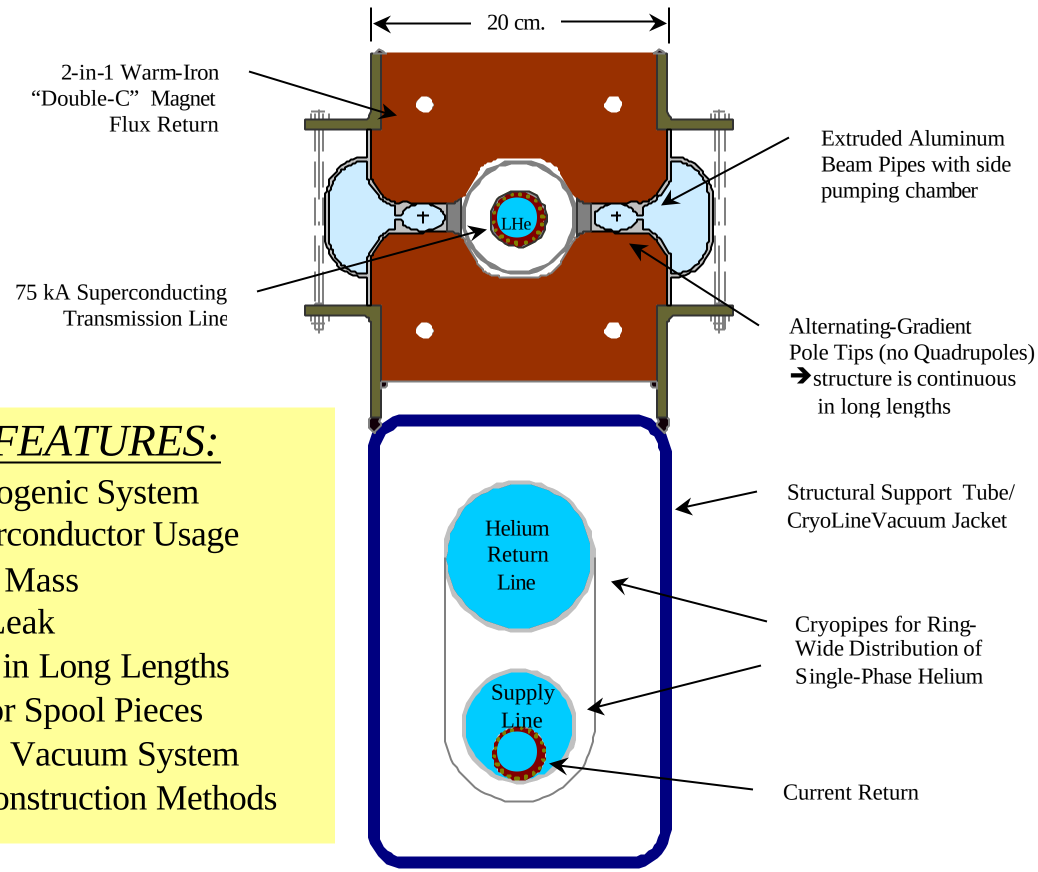
VLHC Magnet Workshop Summary

Common Coil Design



-Field: Bmax=11.1 T at 15 kA
-Good field region: $\Delta B/B<10^{-4}$ @ ϕ<1cm
-Design: two-layer block type
two-bore common coil
-Horizontal bore gap: 30 mm
-Coil cross-section per bore 2588 mm^2
-Strand: Nb_3Sn, ϕ0.7 mm,
Ic(12T;4.2K)=460 A (2kA/mm^2)
-Cable: N=40, 1.18*15.0 mm^2 (rect.)
-Insulation: Kapton or fiber-glass tape
-React & Wind technique
-Fermilab/LBNL collaboration

Transmission Line Magnet

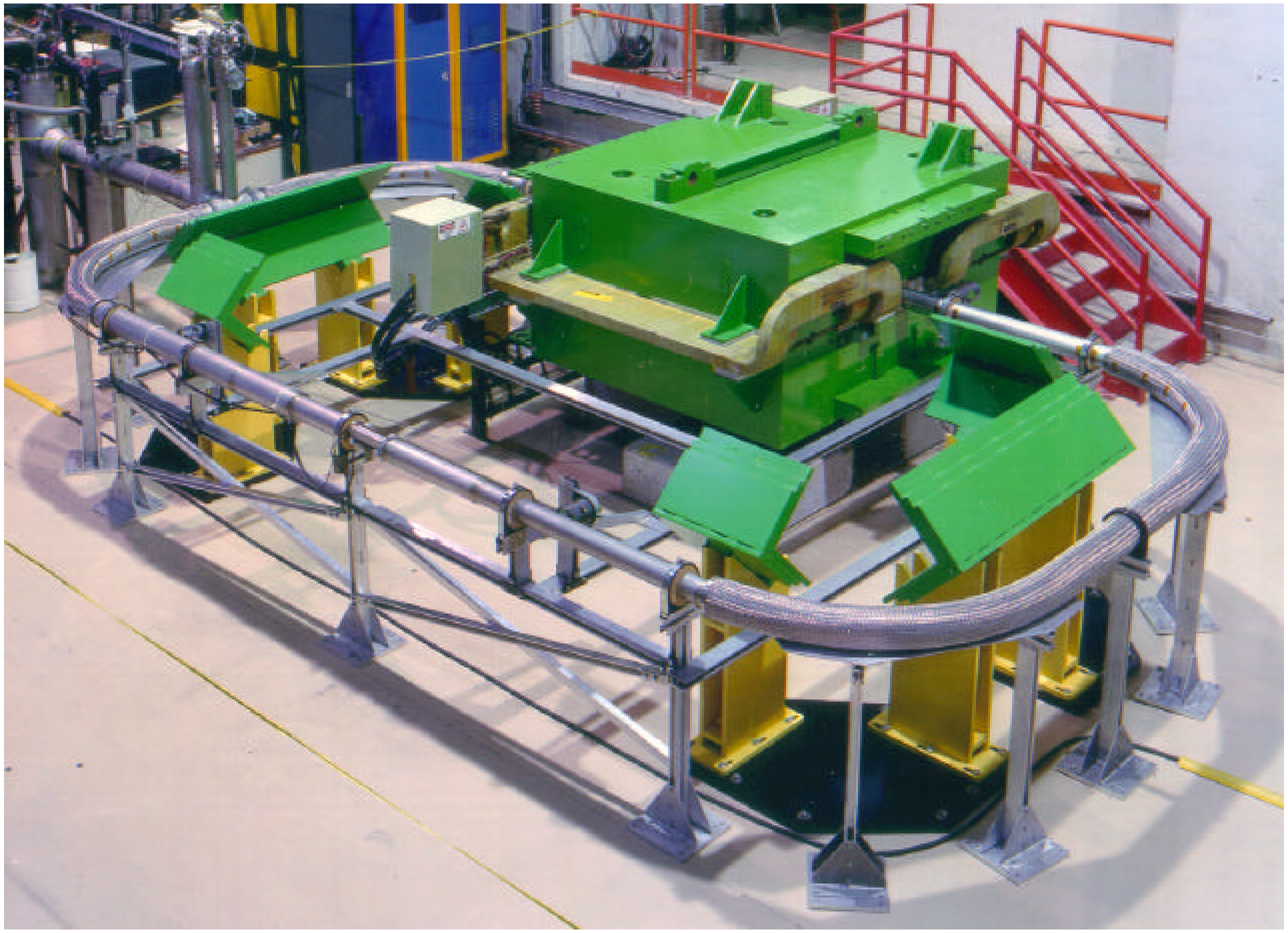


KEY FEATURES:

- Simple Cryogenic System
- Small Superconductor Usage
- Small Cold Mass
- Low Heat Leak
- Continuous in Long Lengths
- No Quads or Spool Pieces
- Warm Bore Vacuum System
- Standard Construction Methods

VLHC Magnet Workshop Summary

Transmission-Line Test Loop



VLHC Magnet Workshop Summary

What's happened since the last magnet workshop?

- No magnets, but there are interesting things happening.
  - *Concepts for staging the VLHC*
  - *Conductor improvements and the start of focused R&D*
  - *Infrastructure buildup and operation*
  - *Some interesting magnet design discoveries*
    - Methods for compensating hysteretic multipoles
    - Successful test of common coils at LBNL
    - Use of CTD ceramic cloth and binder to form coils at Fermilab
    - Excellent field quality designs for all magnets including cos-theta, common-coil and superferric.

Staging the VLHC

- **Favored at Fermilab is an approximately 200 km tunnel, with each step yielding new physics opportunities**
  - A 2 T magnet results in ~50 TeV (cm), and could be a full-size (single turn) injector for higher energy
  - OR, could use a 4 T (à la RHIC or Tevatron) to achieve 100 TeV (cm) as a first or second step
  - A second (or third) step could be 10 T (or higher) for 200 TeV (or higher), injecting in a single turn from first machine

By the way. *A 200 km tunnel would permit a 300 GeV (cm) electron-positron collider with high luminosity and an affordable power bill*

Strand Procurement Status

- **Much improved in the past year**
  - Oxford Superconducting Technologies (OST) has delivered strand with $J_c > 2250$ A/mm^2, in acceptable piece lengths
    - 100 kg to LBNL in July, 1999 (= 600 m of cable)
    - 50 kg to Fermilab in Dec., 1999
    - 40 kg for LBNL in final process
  - Shape Metal Innovations (SMI, Holland) has delivered strand with $J_c = 2250$ A/mm^2, and $d_{eff} < 50$ µm, in acceptable piece lengths in Feb., 2000
  - Intermagnetics General Inc. (IGC) has been able to improve piece lengths and reproduce earlier $J_c = 1950$ A/mm^2. Production for Fermilab, LBNL and TAMU has resumed.

Strand Procurement Status (2)

❖ Started a National R&D Program in Nb3Sn

- First goal is to improve critical current density J_c > 3000 A/mm2 (at 12 T and 4 K) with effective filament diameter d_{eff} < 40 μm and long piece lengths
- Second goal is to scale production and attain cost reduction to equal or below the cost of NbTi (about factor of 4)
- Initially $500 K for FY2000, roughly split between IGC and OST
  - Managed by LBNL
- Hoping to increase amount available in FY2001, and extend technologies to include Powder-in-Tube, Nb3Al, other.
- Add some support for heat treatment and testing

VLHC Magnet Workshop Summary

Magnet Test Infrastructure

1. VMTF: short model magnet test facility

T_{oper} =1.8 - 4.5 K

I_{oper} = 0-18.8 kA

Magnet length - up to 4 m

He volume - 800 liters

2. New horizontal test stand is now under construction.

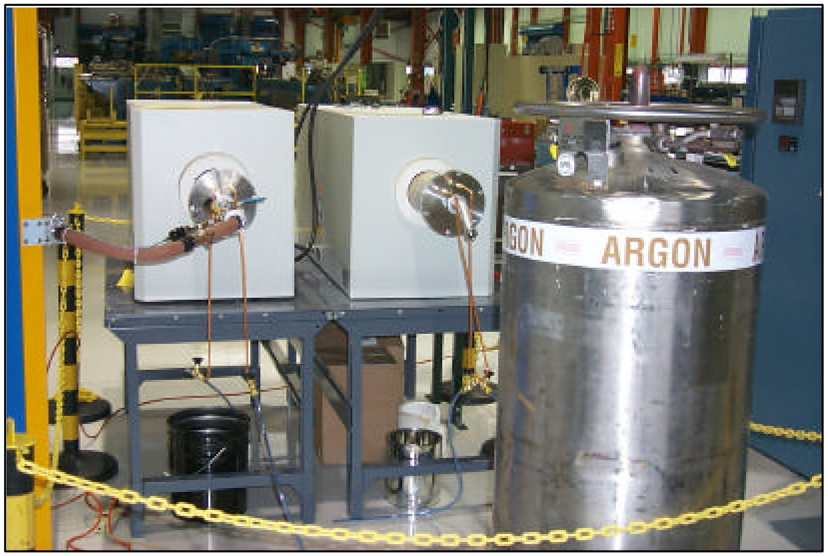
Soon to be upgraded to 25 kA

VLHC Magnet Workshop Summary

Superconductor R&D Infrastructure

Ü **Teslatron (Oxford Instrument Inc.):**

- Field range: 0-17 T
- Current range: 0-1 kA
- Temperature range: 1.5-100 K
- Available bore: 50 mm

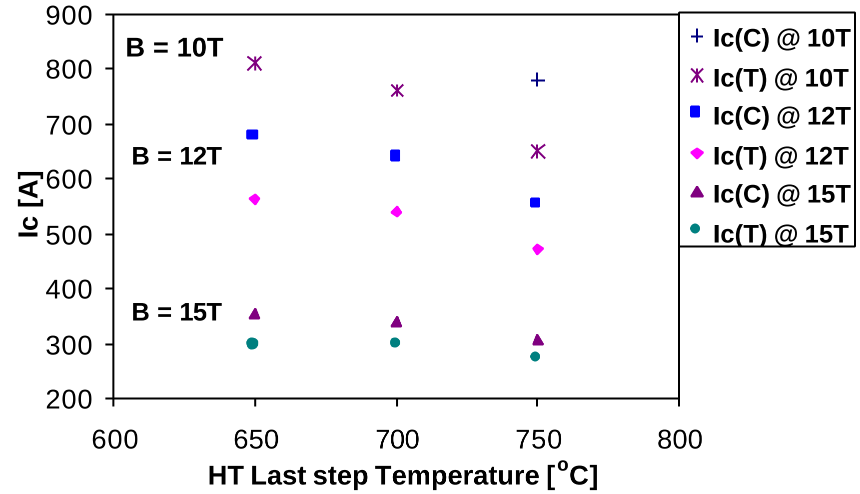


Short sample reaction ovens: Þ

- Temperature range: 0-1100 C
- Available volume: ϕ140mm, L=380 mm

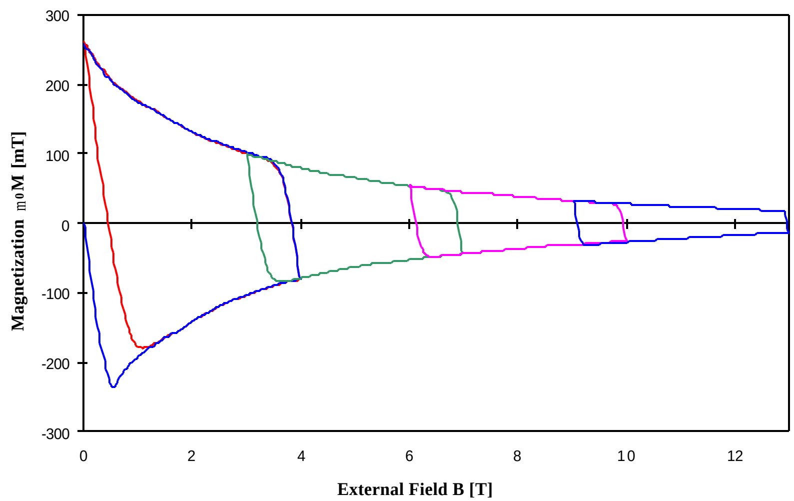
Nb3Sn Strand Study

SC strand characterization:
- Ic(B,T,strain)
- n-value (B,T,strain)
- M(B,T)
- deff
- RRR(B)



Hysteresis Curve

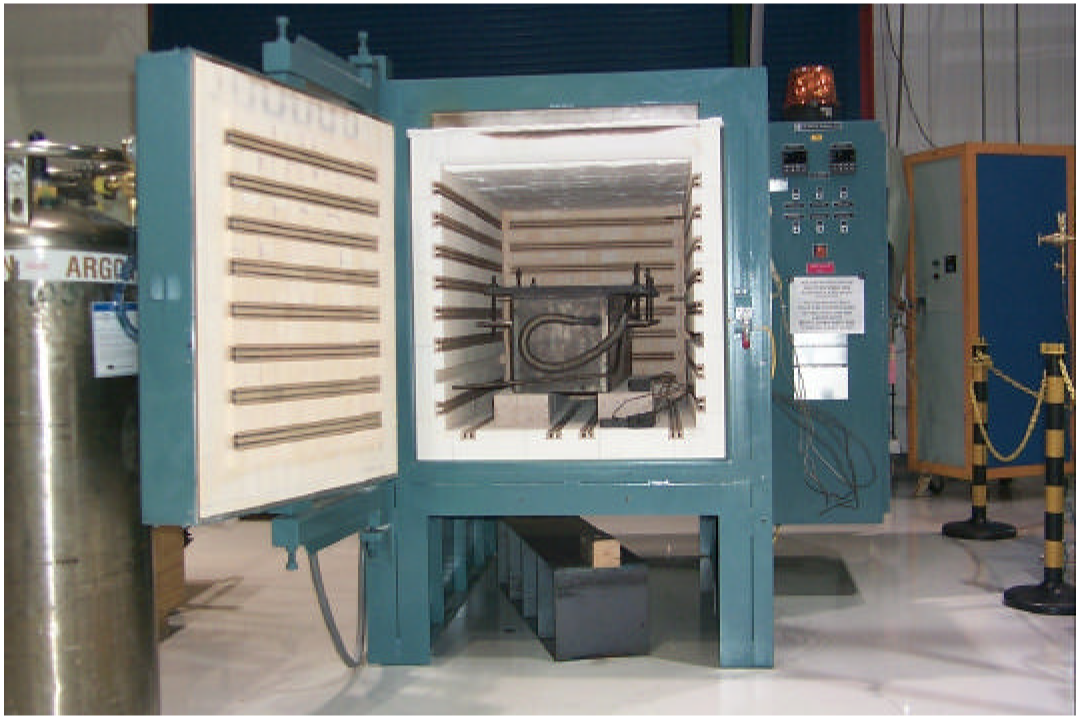
IGC Intermediate Tin Nb_3Sn 61 subelemnts Heat Treatment 5



⇑ Nb3Sn strand critical current vs. heat treatment temperature

⇐ Nb3Sn strand magnetization curve

Nb3Sn Coil Fabrication



Oven and retort for Nb3Sn coil reaction

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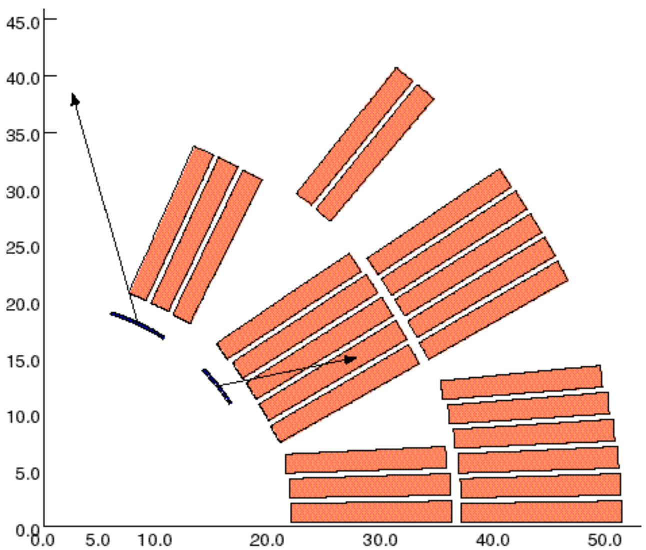
Magnet Fabrication Infrastructure

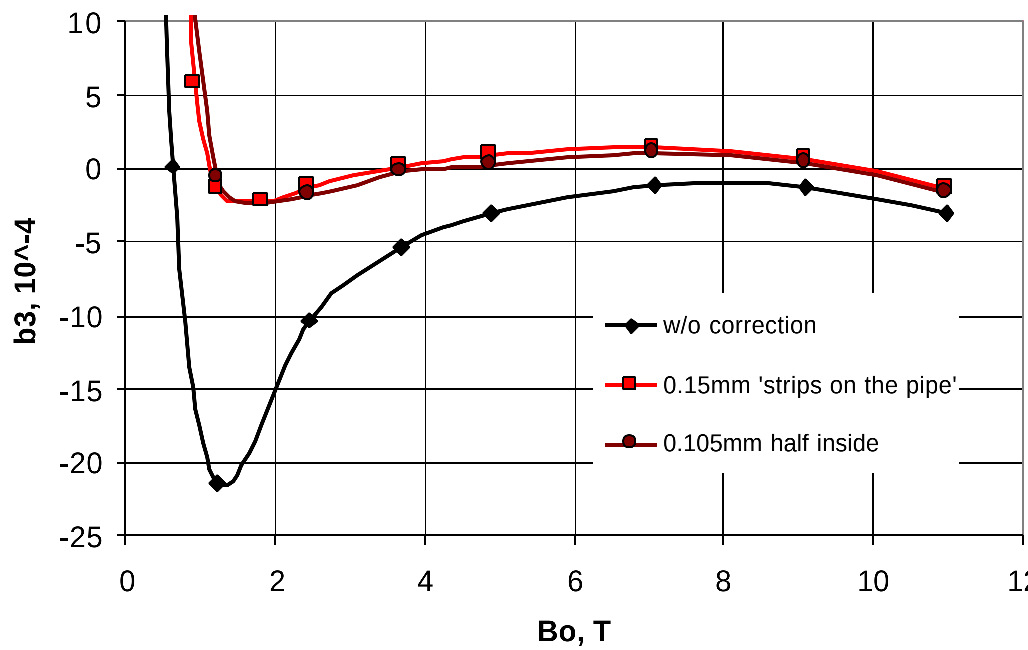
Short model fabrication equipment in IB3

Full-scale magnet production area in ICB

VLHC Magnet Workshop Summary

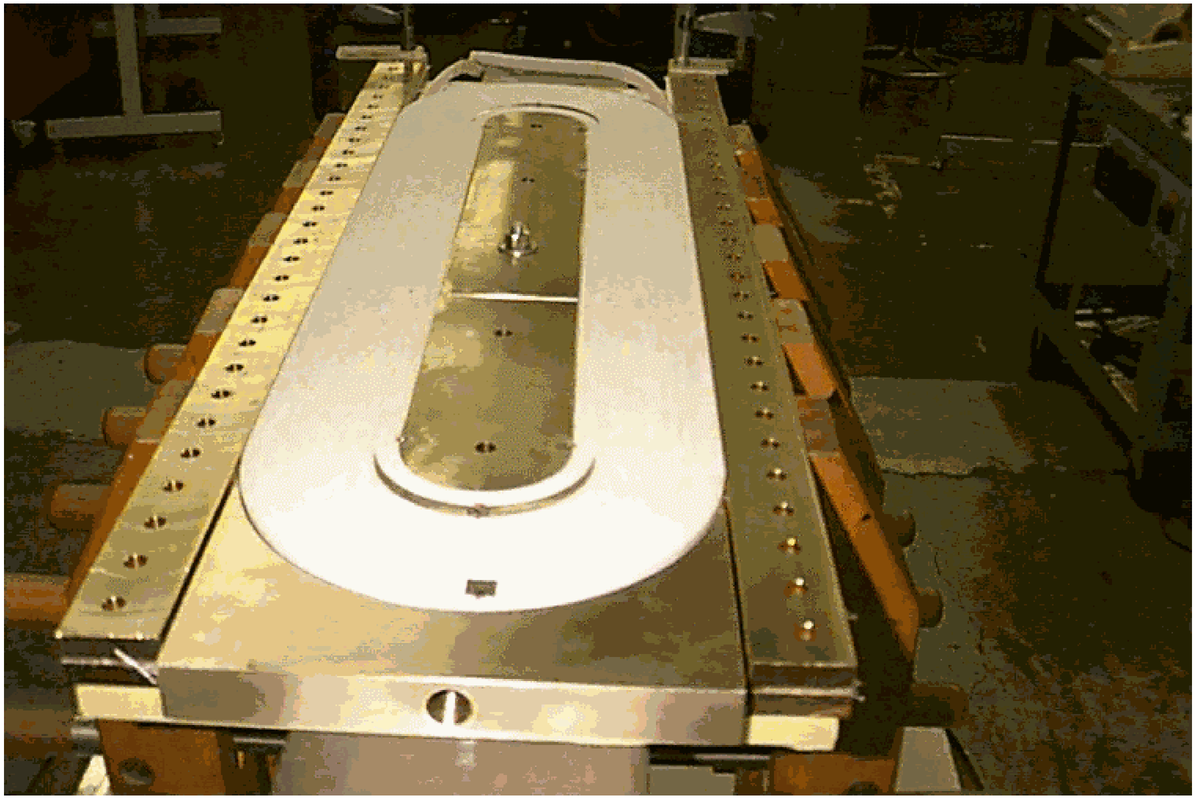
Correction of magnetization and saturation





This new technique permits the use of wire with larger filament diameters, which was a major roadblock to the development of useful high-Jc Nb3Sn.

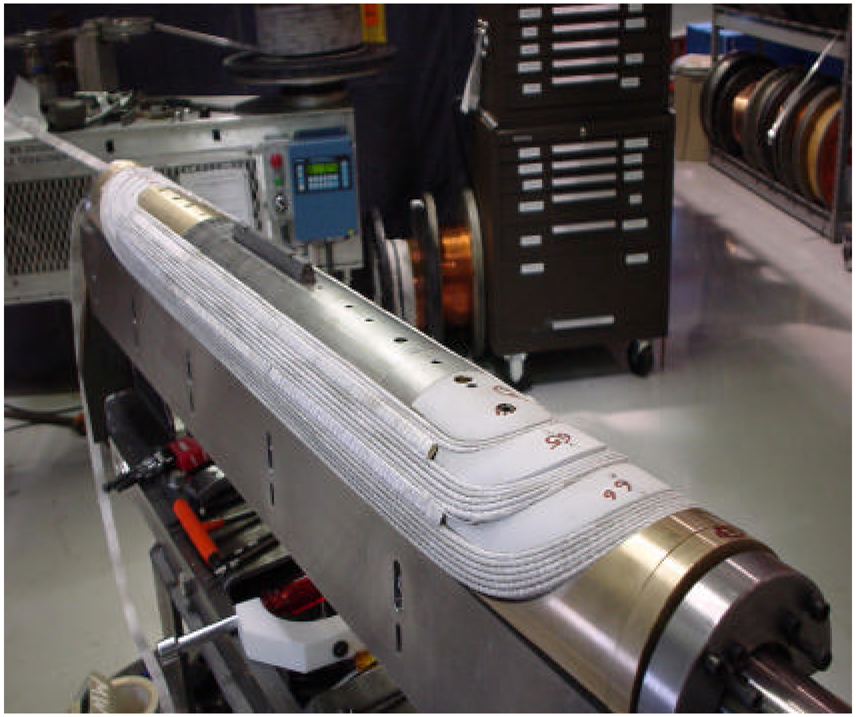
LBNL Outer Racetrack Coil



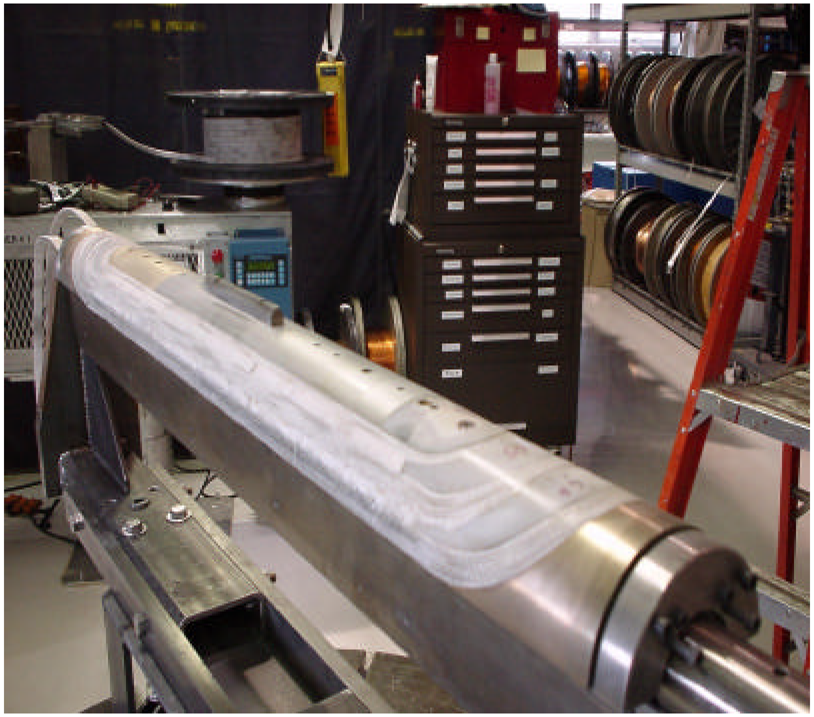
A recent test (Mar. 7) of double outer pancake attained ~12 T with no training, demonstrating the power of the common-coil concept.

Nb3Sn Mechanical Model Coils

Before low-temperature cure



After low-temperature cure



VLHC Magnet Workshop Summary

Some observations

- Some problems that were with us 18 years ago, at the start of the SSC design work, are still with us:
  - *Synchrotron radiation and beam-tube liners. LHC will finally be a real demonstration.*
  - *Margin? Margin is not for operation, it's allows for spread in magnet performance. We should be trying to reduce the spread in magnet performance to reduce margin.*
  - *What field quality do we really need? Does it reduce cost to be able to have worse field quality?*
- Also
  - *Take advantage of the latest technologies: controls, fast calculations, feedback, communication.*
  - *Don't over-design. Take advantage of the results of R&D. Don't invent catastrophes that will never happen.*

VLHC Magnet Workshop Summary

Some more observations

- There will be some shake-out in the R&D program
  - *We should try to control the way this happens, otherwise funding agencies and Directors will control it for us.*
    - For example, I learned at this meeting that the goal of the BNL common-coil R&D has changed to a 12 T, react-and-wind magnet, just as it has been at Fermilab. This will give us the opportunity to cooperate, saving money, infrastructure and personnel resources. We should begin to make this plan. Should this be done through the steering committee?
    - Another example. Very high-field magnets (B>12 T) are interesting and possibly useful for low-energy machines. Are they useful in the context of a VLHC? I doubt it. Wouldn't we be better off devoting those resources to other problems?

Yet some more observations

- The program is alive and breathing, but it's not really healthy.
  - *Look around you. Except for some of the Fermilab staff, we are the same old, gray-haired men. Where is the new blood? What does this signify?*
    - **Not enough support, so leaders are not confident enough to add new staff to their programs.**
      - *Or, perhaps it's just the travel restrictions.*
  - *Each program and the national program is too small. The number of magnets is so small that single failures could kill some of the efforts.*
  - *We haven't gotten the attention of Directors or the HEP community. Is the future too far away?*

VLHC Magnet Workshop Summary

What's Next?

- **Make working magnets!!**
  - **This will happen soon**

- **Cooperate more to save R&D resources**
  - **The individual programs are becoming closer, maybe. We need to arrange this cooperation ourselves.**

- **Start some accelerator physics to inform the magnet programs and attack some of the other issues.**

What's Next?

- Prepare for Snowmass 2001
  - *We will try to have some guidance by the time of the Annual Meeting.*

- ***Overall goals for Snowmass 2001***
  - **To set down the major themes of high-energy particle physics and the experiments and facilities that will be needed to explore those themes.**
  - **To understand the R&D effort needed to carry out the experiments and develop the facilities.**

VLHC Magnet Workshop Summary

Snowmass 2001

- **VLHC-Specific goals for Snowmass 2001**
  - **Our goal will be to have a picture of the VLHC and to describe an R&D program that will permit us to realize that picture.**
    - **What are the major paths of the R&D program?**
    - **What, if any, are the staging possibilities?**
    - **When (and how!) along the R&D path can we make decisions and establish new directions?**
    - **Can we sensibly distribute the R&D work among the various participants?**
    - **What resources and how much time is needed to accomplish the R&D?**

VLHC Magnet Workshop Summary

Thanks!

- John Tompkins
- Hank Glass
- Cynthia Sazama
- Patti Poole
- The Organizing Committee
- The Chairs (very comfortable)
- The DOE (some of whom are paying attention)
- The attendees, foreign & domestic
- Lots of others

It was a great workshop. Let's get busy and do the work.